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Evapotranspiration and Soil Moisture-Fertilizer Interrelations With Irrigated Grain Sorghum in the Southern High Plains

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Washington, D.C. Issued August 1965

Evapotranspiration and Soil Moisture-Fertilizer Interrelations with Irrigated Grain Sorghum in the Southern Great Plains

By Marvin E. Jensen and Willis H. Sletten, *Soil and Water Conservation Research Division, Agricultural Research Service* [1]

In 1956 and 1957 grain sorghum represented 37 percent of the harvested crop acreage in Texas (*14*).[2] The largest concentrated area of sorghum is in the High Plains where the proportion of sorghum irrigated increased greatly during the drought years of the 1950's. In 1959 the monetary value of irrigated grain sorghum was estimated to be about $100 million.

As reported by the U.S. Census of Agriculture, the acreages of irrigated grain sorghum harvested in the 42-county High Plains area in 1950, 1954, and 1959 were 387,000, 1,006,000, and 1,224,000 acres, respectively. The irrigated grain sorghum acreage in the eight counties—Castro, Deaf Smith, Floyd, Hale, Lamb, Lubbock, Parmer, and Swisher—represented over 80 percent of the total in the High Plains in 1954 and 1959.

Development of high-yielding hybrids and a large increase in the number of irrigation wells in the area have been major factors in the threefold increase in irrigated grain sorghum. The number of wells increased from about 8,000 in 1948 to 45,000 in 1958 and 52,000 in 1963. Expansion since 1959 has been mainly north of the Canadian River.

Ideal topography was instrumental in the rapid development of irrigation in the area. It is not uncommon for farmers to irrigate one-half-mile rows without any land smoothing.

The predominant soils in the area, except for Lamb and Lubbock Counties, consist mostly of clay loams and silty clay loams (*10, 15*). The High Plains is perhaps one of the largest irrigated areas having a single predominant soil.

The source of water used for irrigation is an aquifer that underlies most of the area. The total water supply is extensive, but the rate of recharge by rainfall is very small compared to the current rate of pumping. The pumping lift ranges from about 100 to 400 feet in different areas of the High Plains. The cost of pumping water and the growing awareness that the current pumping rates greatly exceed natural recharge created a need for maximizing economic returns per unit of irrigation water and precipitation.

Without irrigation, inadequate precipitation is the major factor limiting crop production in the area. Under nonirrigated conditions, the common cropping sequences involving grain sorghum are continuous sorghum and sorghum after wheat. Bond and coworkers evaluated the frequency of obtaining various yields of grain sorghum under dryland conditions from 1907 to 1919 and 1943 to 1958 on the "hardland" soils in the Texas High Plains (*1*). They found that the yield of continuous grain sorghum was less than 2,000 pounds per acre about 80 percent of the time. With sorghum after wheat (fallow from harvesting of wheat until the next season), the yield was less than 2,000 pounds 70 percent of the time. The yields were less than 800 pounds 20 percent of the time with continuous sorghum and 15 percent of the time with sorghum after wheat. Yields exceeded 2,500 pounds about 5 percent of the time with continuous sorghum and about 15 percent of the time with sorghum after wheat. Commercial fertilizers currently are not needed in dryland sorghum production.

Yields were doubled or tripled during the first 1 or 2 years of irrigation. Yields decreased in subsequent years if nitrogen fertilizer was not used. The purpose of this study was to combine moisture and fertilizer levels in an experiment to provide irrigation and fertilizer recommendations for use by irrigation farmers in the area.

STUDY AREA

Location

The experiment was located on the USDA Southwestern Great Plains Research Center near Bushland, Tex., 14 miles west of Amarillo (latitude 35°15′ N., elevation 3,825 feet). The station is located near the northern edge of the irrigated grain sorghum counties previously mentioned. The soil on the experiment station is representative of the irrigated area to the south as well as to

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[1] The authors gratefully acknowledge the computer services provided by the Data Processing Center, Texas A&M University, and the assistance of Frank O. Wood, Southwestern Great Plains Research Center, Bushland, Tex., in carrying out field operations and processing the voluminous data.

[2] Italic numbers in parentheses refer to Literature Cited, p. 17.

the irrigated area north of the Canadian River. The Canadian River bisects the High Plains in an east-west direction north of the station.

Soil

The soil on the experimental site is Pullman silty clay loam (*3*, *15*). Organic matter content in the 0- to 6-inch depth after several years of tillage ranges from 1.6 to about 2.1 percent, as compared to a native grass site of 2.6 percent. A caliche layer ($CaCO_3$) occurs at a depth of 3.5 to 4 feet. The proportion of $CaCO_3$ by weight in the caliche layer is as high as 45 percent (*15*). The soil of a given layer is extremely uniform in physical properties and moisture-holding characteristics for extensive areas.

Bulk density determinations to a depth of 5 feet were made at four locations on the experimental site on September 18, 1956, by the use of two 1.85- by 4-inch cores per foot of depth. The standard error of the mean of four cores was 0.056, or 3.8 percent of the mean volume weight. These data and soil moisture characteristics are summarized in table 1. Field capacity values given are the mean of high values measured 5 to 10 days after a preplanting irrigation. Wilting percentages are the mean of low values measured near harvest on the drier plots. These field capacity values would not be the maximum obtainable 1 to 2 days after excessive irrigation. However, they indicate available water-holding capacity under normal irrigation practices when evapotranspiration rates are low. The rate of internal drainage by gravity on this soil is very slow. Therefore, when evapotranspiration rates are high, the effective available water-holding capacity is greater than the values given in table 1, because evapotranspiration demands can be met with water that ordinarily drains from the profile in the 5- to 10-day period after irrigation.

TABLE 1.—*Soil density and moisture-holding characteristics, Pullman silty clay loam*

Depth increment	Bulk density	Field capacity [1]	Wilting point [1]	Available water
Inches	*G./cc.*	*Percent*	*Percent*	*Inches*
0–12	1.38	24.6	12.6	1.99
12–24	1.52	22.7	13.5	1.67
24–36	1.52	21.0	13.0	1.46
36–48	1.50	20.4	13.5	1.24
48–60 [2]	1.40	21.9	[3] 13.5	1.41
60–72 [2]	[3] 1.50	19.9	13.4	1.17
Total:				
0–48				6.36
0–72				8.94

[1] On an oven-dry weight basis.
[2] Contains as much as 45 percent $CaCO_3$ by weight.
[3] Estimated.

Low intake rates on these soils limit the amount of irrigation water that can be applied in 12 to 24 hours to 4 to 5 inches during the growing season. A summary of intake measurements made in an adjacent experiment that uses level basins and tillage practices similar to those used in this experiment is presented in table 2. A 4-inch irrigation during the growing season requires about 16 to 20 hours to be absorbed. The intake from 0 to 0.33 hour ranges from 1.9 to 2.3 inches, and the intake from 0.33 to 15.33 hours ranges from 1.7 to 2 inches. Intake rates are higher during the preplanting irrigations. Intake rates when large furrows are used between sorghum rows on

TABLE 2.—*Average intake rates for preplanting irrigations and cropping season irrigations on grain sorghum with sweep-chisel tillage used during the fallow period, Bushland, Tex., 1957–59*

Year	Irrigation	Intake rates for time interval after applying water									Weighted average
		0.33–0.67 hour	0.67–1.33 hours	1.33–2.00 hours	2.00–2.67 hours	2.67–3.33 hours	3.33–4.67 hours	4.67–7.33 hours	7.33–10.67 hours	10.67–15.33 hours	
		In./hr.	*In./hr.*	*In./hr.*	*In./hr.*	*In./hr.*	*In./hr.*	*In./hr.*	*In./hr.*	*In./hr.*	*In./hr.*
1957	Preplant	0.504	0.356	0.252	0.224	0.216	0.168	0.129	0.108	0.080	0.145
	Average (1 and 2)[1]	.638	.279	.161	.122	.140	.118	.104	.083	.081	.110
1958	Average (1 and 2)[1]	.624	.240	.108	.108	.072	.120	.105	.084	.091	.114
1959	Preplant	1.104	.480	.264	.120	.144	.168	.162	.154	.154	.242
	Average (1 and 2)[1]	.457	.156	.108	.120	.108	.120	.096	.082	.084	.128

[1] Average of the 1st and 2d irrigation during the crop season.

these soils should be similar, because of rapid lateral water movement in the plow layer and the dense soil below the plow layer that extends to a depth of about 3 feet.

The soil on the experiment site was first irrigated in 1956. Before 1956, the land was fallowed in 1955 with a previous cropping history of a wheat-sorghum-fallow dryland rotation.

Climate

The weather in the Great Plains is noted for its great variability and rapid changes. Extreme variations in monthly rainfall, daily temperature, and windspeed are normal expectations, especially during the months of March, April, and May. Annual precipitation ranges from less than 10 inches to over 30 inches.

A summary of average climatic conditions and the weather conditions existing during this 4-year study is presented in table 3. The probabilities of receiving various amounts of rainfall are illustrated in figure 1 (*5*). The pattern of precipitation is similar for much of the area, but more precipitation occurs east of Amarillo.

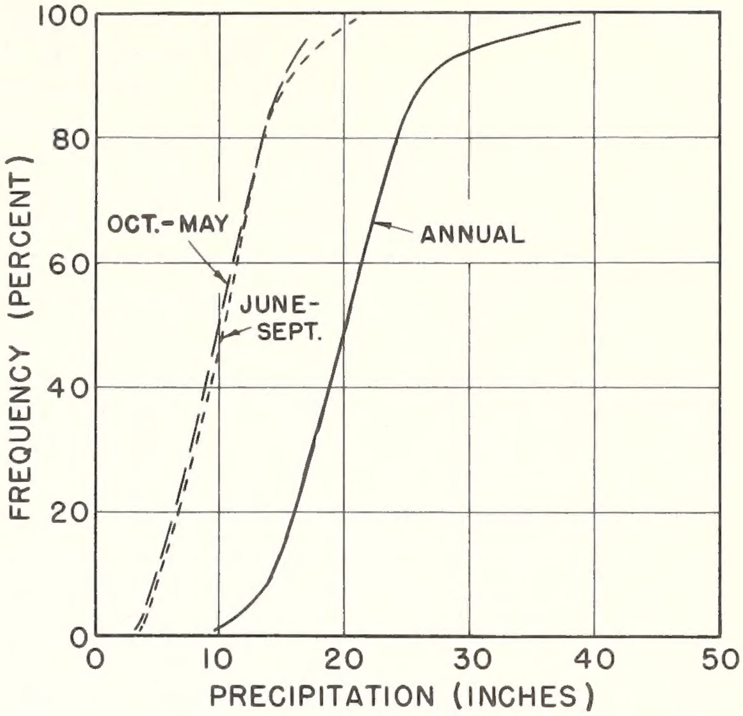

FIGURE 1.—Probability of receiving various amounts of annual, fallow period, and sorghum growing season precipitation at Amarillo, Tex. The curves represent the percentage of time that precipitation can be expected to be less than the amounts shown.

TABLE 3.—*Summary of weather data for the grain sorghum growing season at Bushland, Tex., 1956–61, and averages for longer periods*

Year	Preceding fallow period, November-May, average or total	Crop growing season						Annual average or total[1]
		June	July	August	September	October	Average or total	
	PRECIPITATION (INCHES)							
1956	6.65	1.10	3.18	2.03	0.12	0.32	6.75	13.40
1957	8.62	3.05	1.70	4.22	1.05	2.55	12.57	21.19
1958	9.61	1.77	7.79	.53	2.05	.21	12.35	21.96
1959	6.39	2.69	2.15	2.50	1.13	2.00	10.47	16.86
1939–61	7.20	2.60	2.88	2.51	1.64	1.87	11.50	18.70
	MEAN DAILY MAXIMUM AIR TEMPERATURE (°F.)							
1956	66.2	92.6	92.9	91.7	90.2	80.2	89.5	75.9
1957	63.6	88.6	96.5	89.9	83.3	69.9	85.6	72.8
1958	59.7	93.5	91.0	92.6	85.1	73.3	87.1	71.2
1959	64.4	89.3	89.6	92.1	86.9	72.2	86.0	73.4
1939–61	62.9	89.4	91.3	90.5	84.9	74.6	86.1	72.6
	MEAN DAILY MINIMUM AIR TEMPERATURE (°F.)							
1956	31.0	63.1	63.2	60.8	55.5	46.3	57.7	42.2
1957	33.3	57.4	64.9	62.8	51.3	44.6	56.2	42.9
1958	32.9	60.4	64.3	62.0	57.4	43.7	57.5	43.2
1959	30.3	60.2	61.6	63.5	53.8	39.5	55.7	40.9
1939–61	32.1	59.5	63.3	62.3	54.7	44.1	56.8	42.4

See footnotes at end of table.

TABLE 3.—*Summary of weather data for the grain sorghum growing season at Bushland, Tex., 1956–61, and averages for longer periods*—Continued

Year	Preceding fallow period, November-May, average or total	Crop growing season						Annual average or total[1]
		June	July	August	September	October	Average or total	
MEAN CLOUD COVER (TENTHS)[2]								
1956	4.7	4.2	5.0	3.8	1.1	2.7	3.4	4.1
1957	5.8	4.3	4.1	4.7	3.5	6.2	4.6	5.3
1958	5.9	4.1	4.1	4.0	5.5	4.6	4.5	5.3
1959	4.9	4.7	4.2	4.2	2.6	3.6	3.9	4.5
1955–60	5.1	4.3	4.5	3.9	3.3	4.0	4.0	4.7
ESTIMATED SOLAR RADIATION (G. CAL./CM.^{2}-DAY)[2]								
1956	417	677	615	595	598	430	582	486
1957	379	653	665	555	496	321	538	445
1958	364	661	664	593	491	374	556	445
1959	414	451	654	588	572	404	534	464
Long-time average	393	652	641	598	508	390	558	462
PAN EVAPORATION (INCHES)[3]								
1956	44.26	11.68	11.26	11.49	11.70	8.46	54.59	98.85
1957	33.89	9.54	14.28	9.04	7.63	5.15	45.64	79.53
1958	23.89	11.74	11.18	11.14	8.33	5.92	48.31	72.20
1959	34.32	10.04	9.46	10.00	9.07	5.27	43.84	78.16
1940–61	[4] 33.88	10.81	11.08	10.15	8.35	6.35	46.74	80.62
WINDSPEED (MILES/HOUR)[5]								
1956	6.55	6.36	5.04	4.82	6.04	5.71	5.59	6.15
1957	6.34	5.91	4.86	4.38	4.54	5.68	5.07	5.81
1958	5.61	6.40	6.06	3.72	5.69	3.99	5.16	5.42
1959	6.06	5.44	5.41	5.49	5.79	5.19	5.46	5.81
1939–61	7.08	7.04	5.90	5.53	6.19	5.82	6.09	6.67
RELATIVE HUMIDITY (PERCENT)[6]								
1956	51.9	39.9	43.6	38.6	36.2	42.0	40.1	46.9
1957	46.6	53.9	50.1	55.5	56.2	71.9	57.6	51.2
1958	55.2	38.4	46.0	39.3	51.6	45.8	44.2	50.6
1959	45.4	44.5	41.1	39.8	36.9	49.2	42.3	44.1
1940–61	52.9	48.3	49.3	48.6	49.3	51.4	49.4	51.4

[1] Previous November through October.

[2] Amarillo, Tex.

[3] Young screened ground pan, 2 ft. diameter. (1940–53 U.S. Weather Bureau pan data converted to Young pan by a coefficient of 0.92.)

[4] 11-year average for October through March.

[5] Height of anemometer, 1.75 ft.

[6] Average of 8:00 a.m., noon, and 4:30 p.m. values.

PROCEDURE

Experimental Design

The experimental design was a randomized complete block with split plots. Four replications of six soil moisture levels as complete blocks and six fertilizer treatments as split plots were used. Each moisture level was included in a level basin diked on all sides with level area dimensions of 30 by 165 feet. Depth of irrigation water applied was based on dimensions from center to center of the dikes, 33.3 by 168 feet. Fertilizer plots were 15 by 50 feet. The treatments were maintained on the same plots for the four seasons. (Farmers frequently grow sorghum on the same field 3 to 5 years in succession.)

Moisture Levels

A preplanting irrigation was given all moisture treatments each year several weeks before planting to wet the soil to a depth of about 6 feet. Moisture levels are described below.

Code No.	*Moisture level*
M_1	Preplanting irrigation only.
M_2	One 4-inch irrigation 1 week prior to boot stage.
M_3	Irrigated when the weighted mean soil moisture tension approached 9 atmospheres.
M_4	Irrigated when the weighted mean soil moisture tension approached 4 atmospheres.
M_5	Irrigated when the weighted mean soil moisture tension approached 1½ atmospheres.
M_6	Irrigated the same as M_3, for the first irrigation, and irrigated the second time before the soil moisture tension approached 4 atmospheres in 1957, 1958, and 1959. Irrigated the same as M_4 in 1956, except the third irrigation was not given.

The weighted mean soil moisture tension was obtained by weighting tensions in successive quarters of the moisture depletion zone by 4, 3, 2, and 1. The weighting procedure was based on typical soil moisture extraction patterns. Soil moisture tension was measured indirectly by cured plaster of paris moisture blocks (*2*) calibrated in a pressure membrane apparatus. Calibration consisted of placing six blocks selected at random in a special-built pressure membrane apparatus with 1 cm. of soil above and below the block. Individual leads for each block in the pressure membrane were used. The calibration curve was adjusted to 70° F. and used without further correction. The curing process consisted of at least two 24-hour soaking and drying cycles. The standard deviation of the resistance of individual cured blocks immersed in tapwater was about 25 ohms. The curing process removed most of the drift in calibration that normally would have occurred in the field and some of the variability between blocks. New moisture blocks were installed each summer at depths of 4, 9, 16, 29, and 42 inches in the F_3 and F_5 fertility subplots of each moisture treatment. Readings were made three times a week during the main part of the crop season.

A summary of dates, depths of water applied, and stage of growth at each irrigation is given in table 10 in the appendix. Water from a well was delivered and measured to each moisture plot by the use of gated aluminum pipe and a flowmeter. A summary of rainfall by storms received during the growing seasons as recorded in a gage near the plots is presented in table 11 in the appendix. The sums of these values by months differ somewhat from those presented in table 3 because of location.

Fertilizer Treatments

Nitrogen in the form of ammonium sulfate (20.6 percent N) and phosphorus in the form of concentrated superphosphate (45 percent P_2O_5) were used at the rates given below each year except in 1957. No fertilizer was applied in 1957, because response to applied fertilizer did not occur in 1956, the first year of irrigation.

Fertilizer treatment No.	*Nitrogen (Lb./acre)*	*Phosphorus (45 percent P_2O_5) (Lb./acre)*
F_1	240	0
F_2	0	30
F_3	60	30
F_4	120	30
F_5	240	30
F_6	240	60

In 1956, nitrogen was broadcast on the surface of the soil and worked into the top 2½ inches of soil. In 1956, phosphorus placed with the seed restricted the germination to some extent, owing to limited soil moisture conditions. Consequently, all plots were irrigated on June 26 and June 27 to improve the stand. In 1958 and 1959 nitrogen was broadcast just ahead of each furrow opener and phosphorus placed ahead of the press wheel following the furrow opener (just above the seed).

Cultural Practices

Tillage

In 1956 and 1957 the plots were sweep-plowed to a depth of 6 to 8 inches after harvest. Other tillage operations varied from year to year according to weed and volunteer sorghum growth. After the preplanting irrigation, usually given early in June or late in May, the plots were sweep-plowed to a depth of 2 to 3 inches and spike-tooth harrowed prior to planting to control volunteer sorghum growth and prevent large drying cracks.

Seeding and Harvesting

Plots were planted each year with RS–610 hybrid grain sorghum in rows 20 inches apart. Planting date, rate, and harvest dates were as follows:

Date of planting	*Planting rate (Lb./acre)*	*Harvest dates*
1956—June 13–14	15	Oct. 4–Nov. 2
1957—June 22	11	Oct. 29–30
1958—June 16–17	18	Oct. 6–16
1959—June 17–18	6	Oct. 10–23

The rate of planting used in 1959 was considered to be the minimum for maximum yields based on other studies (*13*).

Yield Determination and Disposal of Crop Residue

Yields were determined by hand-cutting heads, which were dried and threshed at a later date, except in 1956. In 1956, 4 rows, 40 feet long, were harvested from each subplot with a small self-propelled combine. In 1957, 1958, and 1959, 4 rows, 25 feet long were hand-harvested. After hand-harvesting to determine yields, the rest of the plot area was harvested with a combine. Each year the residue was returned to the individual plots, except in 1957. In 1957, an offset combine was used that deposited the threshed stalk to the side of the plot. The stubble remaining after harvest was shredded either in the fall or in the spring and disked into the surface.

Evapotranspiration Determinations

Evapotranspiration (E_t) was determined from soil samples taken periodically to depths of 4 or 6 feet on the F_2, F_4, and F_5 subplots of each moisture level. Samples were taken by hand in 1956, partially by machine in 1957, and by machine in 1958 and 1959 (*9*).

Soil sampling sites were marked so that successive cores could be taken about 1 foot or less from the preceding location moving in the same direction each time. After removing the core, the hole was filled with surface soil and tamped. Because of the low intake rates and limited depths of water applied, the rate of E_t during an irrigation period (from the date of sampling prior to an irrigation to the date of sampling after an irrigation) was calculated as follows:

$$\frac{\text{Inches}_1 + (\text{Irrigation and rainfall}) - \text{Inches}_2}{\text{Days between sampling dates}} = \text{Inches per day}$$

where inches$_1$ and inches$_2$ represent the total water in the profile before and after irrigating. The depth of irrigation water applied was generally less than the amount required to bring the soil to field capacity with the exception of the first irrigation in 1956, which was applied to improve the germination and uniformity of stand.

Values obtained by this procedure for the irrigation period usually were somewhat larger than those obtained between sampling dates after an irrigation. This method of calculation for the irrigation period assumes that each subplot receives the same depth of water and no deep percolation occurs. Small differences in intake between fertilizer subplots due to small differences in soil moisture content may have occurred from 1957 through 1959. The 1959 seasonal total E_t was from the first to the last sampling date; for the other years an adjustment was made back to the date of planting.

Other Measurements

Nitrogen content of the grain was determined each year from 1956 through 1958 and in 1960. The percentage of protein was obtained by using a constant ratio between nitrogen content and protein content. Detailed evaluation of total nitrogen uptake on three moisture levels with four rates of nitrogen was carried out in 1957 and 1958. The results of the nitrogen study have been previously published (*11*). Height determinations were made with a surveyor's rod, and the average height of the grain sorghum was observed at full growth. The relative date of heading was determined when the earliest plots were blooming. A numerical rating was used as follows: (1) late boot stage, (2) beginning to head, (3) partially headed, and (4) headed and blooming. The number of heads per unit area was determined as the plots were hand-harvested. Test weight of the grain was determined by standard volumetric and weighing procedures.

RESULTS AND DISCUSSION

Evapotranspiration

The High Plains is not a large homogeneous irrigated area. Irrigated fields are intermixed with rangeland and nonirrigated farmland. The total acreage of irrigated crops in 1954 other than wheat, a winter crop, represented only about 10 percent of the total land area in the High Plains. In the eight-county area, which had 84 percent of the irrigated grain sorghum in the High Plains in 1954, the total acreage of irrigated crops, other than wheat, represented only 38 percent of the land area. Thus, even during the summer season, about two-thirds of the area is nonirrigated. Evapotranspiration determinations made in this 2.8-acre site surrounded by irrigated and nonirrigated land should be representative of irrigated fields surrounded by nonirrigated land in the area.

Seasonal Evapotranspiration

A detailed summary of seasonal evapotranspiration (E_t) and analysis of variance for three fertility subplots on each moisture level are presented in table 12 in the appendix. Some of these data have been summarized and published earlier (*6, 7, 8*).

The largest yields and the highest water use efficiency were obtained on the M_4 moisture level. Therefore, the M_4 moisture level will be referred to as the optimum moisture level in the rest of this report. Cumulative E_t averaged for the F_4 and F_5 fertilizer plots in 1957–59 and all fertilizer treatments in 1956 on the M_4 moisture level is presented in figure 2. The 4-year average seasonal E_t was about 22 inches.

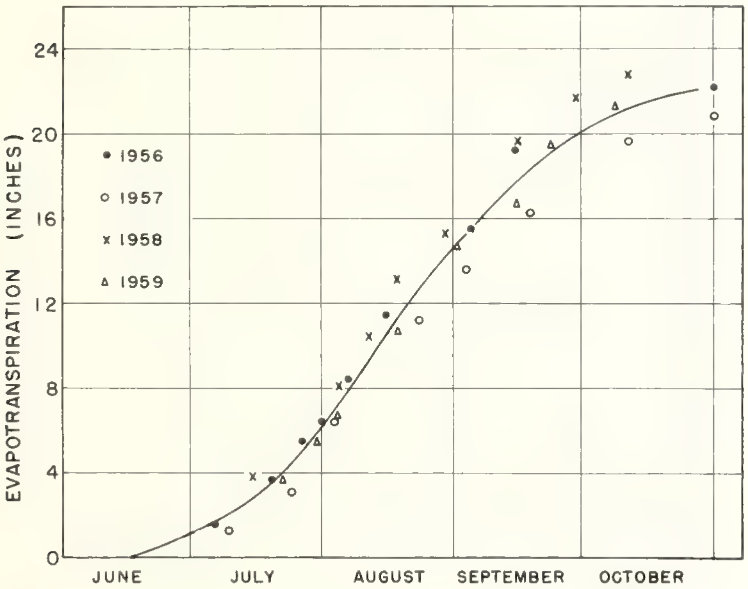

FIGURE 2.—Cumulative evapotranspiration for grain sorghum at Bushland, Tex., with optimum soil moisture conditions (M_4 moisture level).

Climatic conditions during the 1956 growing season were nearly normal except in September and October, when solar radiation and air temperature were above normal and rainfall was below normal. Cumulative E_t in 1956 closely followed the 4-year mean except in September, when it exceeded the mean. The total 1956 seasonal E_t probably would have been higher if an additional irrigation had been given in September. With below-normal rainfall in September and October, most of the available soil moisture was depleted by early October.

Low cumulative E_t in 1957 was a result of below-normal solar radiation and air temperatures, especially in October. Solar radiation and air temperature were above normal in July 1957; however, the planting date was about a week later than average, which apparently resulted in below-normal cumulative E_t that month.

In 1958 heavy July rainfall (7.79 inches) may have caused some deep percolation beyond the soil sampling zone. Soil moisture in mid-July was greater in the 4- to 5-foot and 5- to 6-foot depths than that at corresponding depths on June 23. Also evaporation losses from the soil surface may have been above normal in July because of frequent rains.

Use of nitrogen fertilizer increased yields substantially but had little influence on the seasonal E_t (appendix table 12). For example, with the M_4 moisture level, the 3-year average yield (1957–59) was 194 percent greater on the highest nitrogen treatment than on the 0-nitrogen treatment, but the average seasonal E_t was only 6.2 percent greater. In 1959, with a lower yield on the 0-nitrogen treatment, the yield was 262 percent greater on the high-nitrogen treatment. The larger yield in 1959 was obtained with an increase of only 5.7 percent in E_t. There was no significant difference in E_t between the 120- and 240-lb. N rate. Similar results have been reported for other areas (*16*).

During August, grain sorghum can be considered as having adequate evaporation and transpiring surfaces so as not to limit E_t. Consequently, an estimate of mean evaporative demand or potential E_t should be approximately the same as the mean E_t determined on the M_4 moisture level during this period. Potential E_t as used here refers to evaporative demand in irrigated fields located in arid and semiarid areas. The 4-year average E_t for August was 8.6 inches (fig. 2). The average total radiation for August was 583 calories per square centimeter per day, which would be equivalent to the energy required to evaporate about 0.389 inch per day. The mean air temperature was 76.9° F. Jensen and Haise (*4*) obtained the equation $E_{tp}=(0.14T-0.37)R_s$ for estimating potential E_t by correlating measured E_t from crops other than grain sorghum with solar radiation and mean air temperature. T is the mean air temperature in degrees Fahrenheit, R_s is solar radiation expressed as evaporation equivalent, and E_{tp} is estimated potential evapotranspiration. With this equation the estimated mean potential E_t during August at Amarillo is 8.5 inches.

Rate of Evapotranspiration

The average rate of evapotranspiration for sampling periods on the M_4 moisture level for the 4 years is presented in figure 3 along with estimated mean potential E_t. Estimated mean evaporative demand or potential E_t is high in June and July up to about the first part of August, then it begins to

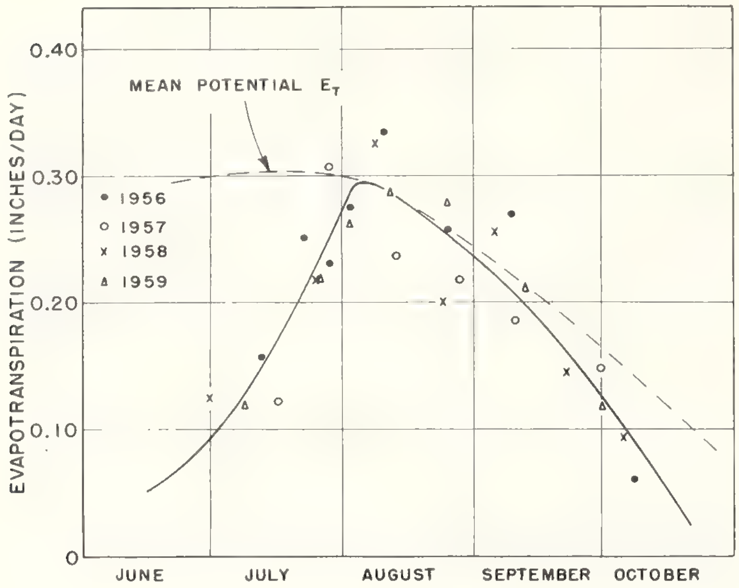

FIGURE 3.—Rate of evapotranspiration (E_t) for grain sorghum at Bushland, Tex., with optimum soil moisture conditions and estimated mean potential E_t.

decrease. The E_t rate was much less than the potential in June and early July because of limited transpiring surface area. As transpiring surface area increased in July, the mean E_t rate increased rapidly until the potential rate was reached during the first few days in August. The decrease in mean E_t rate during August follows the decrease in potential E_t. The effects of crop maturation and lower soil moisture levels appear to have reduced E_t below the potential during the latter part of September and in October. The mean rate of evapotranspiration shown in figure 3 should be applicable to irrigated fields in the area planted to grain sorghum about June 15. For sorghums planted 2 or 3 weeks earlier, the peak rate of E_t will be reached about 10 days earlier.

A summary of total water in the 0- to 4-foot depth for all moisture levels by sampling dates is presented in table 13 in the appendix. These values are the average of the F_4 and F_5 plots. Total water in the 4- to 6-foot depth increment is presented in table 14. Soil moisture extraction from the 4- to 6-foot depth was small except on the dry treatments. Therefore, this depth was not sampled each time the 0- to 4-foot depth was sampled.

Grain Yield

Grain yields for each combination of moisture level and fertilizer treatment and a summary of the analysis of variance are presented in table 4. Yields were greatly affected by nitrogen fertilizer, especially where soil moisture did not restrict yields. No significant response to phosphorus occurred in the 4 years, with average yields of the same treatment as high as 7,200 lb./acre.

Nitrogen fertilizer did not increase yields in 1956. Yields ranged from less than 1,000 lb./acre with a preplanting irrigation only to over 6,000 lb./acre on the M_4 moisture level plots. Severe lodging occurred on the M_2 and M_6 moisture levels due to charcoal rot (*Macrophomina phaseoli*). Moderate lodging occurred on the M_3 and M_5 and some lodging occurred on the M_4 plots. Lodging was more severe on the plots fertilized at the 240-lb./acre nitrogen rate. The M_1 moisture level plots had very little lodging.

A response to nitrogen applied in 1956 occurred on the higher soil moisture levels in 1957. The yield without applied nitrogen was less on the optimum moisture level than on the medium level, apparently because about 1,600 lb./acre more grain was produced on this treatment in 1956. The M_1 moisture level plots lodged, and some lodging occurred on the M_2 level.

In 1958, the third year of irrigation, yields dropped about 50 percent without nitrogen fertilizer on the medium and optimum soil moisture levels. With a preplanting irrigation only, the yield was largest without applied nitrogen.

In 1959, the fourth year of irrigation, yield without applied nitrogen decreased to about 3,000 lb./acre on the optimum soil moisture level. The largest increase in yield occurred with the first increment of nitrogen (60 lb./acre) applied in 1956, 1958, and 1959.

The 4-year average yield with a preplanting irrigation only was about 2,500 lb./acre. On this treatment a slight response to applied nitrogen occurred in 1959. Similar results were obtained on the M_2 moisture level (preplanting plus one seasonal irrigation), except a substantial response to nitrogen fertilizer occurred during the fourth year. In this case, the 4-year average yield without applied nitrogen was about 4,080 lb./acre, whereas the average yield with applied nitrogen was about 4,400. Most of this difference occurred in 1959. In 1959, the plots without applied nitrogen yielded only about 3,300 lb./acre compared with the fertilized plots that yielded as high as 4,590 lb./acre.

On adequately fertilized plots of the medium moisture level (M_3), which averaged about 5,800 lb./acre, a response to residual nitrogen occurred during the second year under irrigation. By the fourth year, yields increased from 3,200 to 5,700 lb./acre with applied nitrogen. These results indicate that, when irrigating for a yield potential of 6,000 lb./acre, no nitrogen fertilizer may be necessary the first 2 years this soil is irrigated but about 60 lb. of N will be needed the third year and between 60 and 120 lb. the fourth year.

With average yields of 7,000 to 7,500 lb./acre, a response to nitrogen occurred during the second year under irrigation. By the fourth year, nitrogen increased yields from about 3,000 to 7,800 lb. per acre. Continuous production of 7,000 lb. per acre, or more, would require at least 120 pounds or more of nitrogen annually.

TABLE 4.—*Effect of soil moisture and fertilizer treatments on the yield of hybrid grain sorghum for 1956–59, Bushland, Tex.*

YIELD DATA

Year	Fertilizer treatment			Yields at moisture level of—						Average for all moisture levels
	No.	Nitrogen	P_2O_5	M_1	M_2	M_3	M_4	M_5	M_6	
		Lb./acre	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Lb./acre*
1956	F_1	240	0	633	2, 161	4, 992	6, 704	5, 433	4, 379	4, 050
	F_2	0	30	780	1, 924	4, 865	6, 462	5, 241	3, 590	3, 810
	F_3	60	30	645	2, 214	5, 176	6, 213	5, 870	3, 909	4, 004
	F_4	120	30	703	2, 026	4, 898	6, 888	5, 286	4, 134	3, 989
	F_5	240	30	817	2, 030	4, 158	6, 450	5, 266	3, 942	3, 777
	F_6	240	60	829	2, 108	4, 477	6, 571	4, 947	3, 958	3, 815
Average				735	2, 077	4, 761	6, 548	5, 340	3, 985	3, 908
1957	F_1	0	0	3, 436	6, 193	6, 735	7, 643	7, 780	6, 964	6, 459
	F_2	0	0	3, 319	5, 860	5, 762	5, 220	5, 330	6, 363	5, 309
	F_3	0	0	3, 541	5, 755	6, 167	6, 539	5, 808	6, 213	5, 670
	F_4	0	0	3, 697	5, 762	6, 755	6, 755	6, 716	6, 526	6, 035
	F_5	0	0	3, 770	6, 030	6, 605	7, 499	7, 637	7, 160	6, 450
	F_6	0	0	3, 567	6, 056	7, 023	7, 434	7, 904	6, 983	6, 494
Average				3, 555	5, 942	6, 508	6, 848	6, 862	6, 701	6, 069
1958	F_1	240	0	2, 058	4, 886	6, 128	7, 258	6, 924	6, 657	5, 652
	F_2	0	30	2, 979	5, 226	3, 554	3, 442	3, 325	3, 848	3, 729
	F_3	60	30	2, 718	5, 500	5, 925	6, 448	5, 938	6, 350	5, 480
	F_4	120	30	2, 626	5, 089	6, 212	6, 964	6, 781	6, 317	5, 665
	F_5	240	30	2, 430	5, 258	6, 219	7, 232	7, 075	6, 650	5, 811
	F_6	240	60	2, 116	5, 526	6, 578	7, 492	7, 029	6, 748	5, 915
Average				2, 488	5, 248	5, 769	6, 473	6, 179	6, 095	5, 375
1959	F_1	240	0	3, 412	4, 176	5, 254	7, 215	7, 770	6, 019	5, 641
	F_2	0	30	2, 803	3, 320	3, 215	2, 980	2, 947	2, 521	2, 964
	F_3	60	30	3, 300	4, 274	5, 058	5, 882	5, 692	6, 156	5, 060
	F_4	120	30	3, 392	4, 496	5, 777	7, 143	7, 117	5, 934	5, 643
	F_5	240	30	3, 281	4, 588	5, 718	7, 822	7, 698	5, 967	5, 846
	F_6	240	60	3, 634	4, 921	5, 535	6, 934	7, 555	6, 810	5, 898
Average				3, 304	4, 296	5, 093	6, 329	6, 463	5, 568	5, 175
Average	F_1			2, 385	4, 354	5, 777	7, 205	6, 977	6, 005	5, 450
	F_2			2, 470	4, 082	4, 349	4, 526	4, 211	4, 080	3, 953
	F_3			2, 551	4, 436	5, 582	6, 270	5, 827	5, 657	5, 054
	F_4			2, 604	4, 343	5, 910	6, 938	6, 475	5, 728	5, 333
	F_5			2, 574	4, 476	5, 675	7, 251	6, 919	5, 930	5, 471
	F_6			2, 536	4, 653	5, 903	7, 108	6, 894	6, 125	5, 530
Overall average				2, 520	4, 391	5, 533	6, 550	6, 211	5, 587	5, 132

ANALYSIS OF VARIANCE

Component	Degrees of freedom	Mean squares [1]			
		1956	1957	1958	1959
Moisture (M)	5	111, 257, 911**	39, 197, 156**	52, 403, 100**	35, 658, 200**
Error (a)	15	683, 301	504, 222	258, 600	326, 300
Fertilizer (F)	5	342, 250	5, 836, 120**	17, 854, 600**	30, 267, 400**
M × F	25	229, 627	794, 681**	2, 173, 800**	2, 168, 700**
Error (b)	90	306, 509	258, 694	246, 591	195, 171
Total	143				

[1] **=Significant at the 1-percent level.

TABLE 5.—*Effect of residual nitrogen and previous moisture levels on yield of hybrid grain sorghum in1960*

YIELD DATA

Fertilizer treatment[1]			Yields at moisture treatment[2] of—						Average for all moisture levels
No.	Nitrogen	P_2O_5	M_1	M_2	M_3	M_4	M_5	M_6	
	Lb./acre	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Lb./acre*
F_1	240	0	6, 486	6, 878	6, 825	6, 480	6, 506	6, 591	6, 628
F_2	0	30	5, 220	4, 026	3, 354	3, 276	3, 132	3, 622	3, 772
F_3	60	30	6, 519	5, 031	3, 967	4, 006	3, 576	4, 144	4, 541
F_4	120	30	6, 767	5, 174	4, 940	4, 561	4, 372	4, 633	5, 075
F_5	240	30	7, 386	6, 584	7, 478	6, 741	6, 297	7, 393	6, 980
F_6	240	60	7, 654	7, 047	7, 360	5, 938	6, 584	6, 055	6, 773
Average			6, 672	5, 790	5, 654	5, 167	5, 078	5, 406	5, 628

ANALYSIS OF VARIANCE

Component	Degrees of freedom	Mean squares[3]
Moisture (M)	5	8, 070, 671**
Error (a)	15	469, 260
Fertilizer (F)	5	43, 551, 814**
M × F	25	1, 039, 166**
Error (b)	90	329, 169
Total	143	

[1] Applied in 1956, 1958, 1959.

[2] 1956, 1957, 1958, 1959; adequate moisture supply in 1960.

[3] **=Significant at the 1-percent level.

The results of this study illustrated the primary interaction between nitrogen and soil moisture levels; i.e., when available soil moisture limited production, applied nitrogen requirements were reduced, and when soil moisture was not the limiting factor, applied nitrogen requirements were greater to obtain good yields. Also, when sufficient water was applied for average yields of about 7,000 lb./acre, the production without nitrogen fertilizer decreased the second year this soil was irrigated and continued to decrease as the reserve of available N was depleted.

In 1960, the experimental site was irrigated uniformly to evaluate the effects of residual nitrogen and previous moisture levels on yield (table 5). The 1960 yields on the F_2, F_4, and F_5 treatments were inversely related to amount of irrigation water and directly related to the amount of nitrogen applied during the previous 4 years. No significant yield response to phosphorus occurred.

Yield of grain sorghum was not materially affected by soil moisture level if the average available soil moisture in the 0- to 4-foot depth just prior to irrigations was more than 30 percent. Yields from the F_5 fertilizer treatment (and F_4 if the yield on the F_4 was not more than 2 or 3 percent less than the F_5 yield) on the M_3, M_4, and M_5 moisture levels were used to evaluate this effect (fig. 4). The curve in figure 4 was fitted by eye. Yields were greatly reduced when the average available soil moisture level was less than 25 percent before irrigations. A similar pattern of reduction in yield as influenced by the soil moisture level reached prior to irrigation was observed by Musick, Grimes, and Herron on Richfield soil at Garden City, Kans. (*12*).

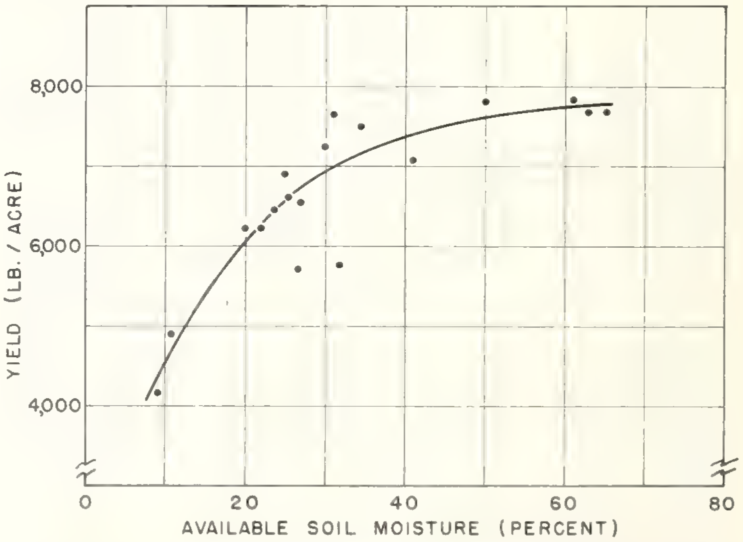

FIGURE 4.—Available soil moisture in the 0- to 4-foot depth prior to irrigations can be depleted to an average of 30 to 40 percent before yields are materially reduced.

The soil moisture extraction pattern was evaluated during sampling periods when little or no rainfall occurred. The results indicated that as the season progresses from July 15 to September 15, the percentage of soil moisture obtained from the top foot during a sampling period decreased from about 50 to 35 percent. The percentage of extraction from the other depths to 4 feet increased during this period.

Delaying irrigations until small amounts of available water remained in the upper layers of soil decreased total seasonal E_t, but yields decreased by a greater proportion. This relation was evaluated by considering the average seasonal E_t on the F_4 and F_5 fertilizer plots of the M_4 moisture level as E_t with optimum soil moisture (E_{to}). The yield on the F_5 fertilizer treatment on the M_4 moisture level was used as the maximum ($Y_{\max}$). The data presented in figure 5 are mean relative yields ($Y/Y_{\max}$) on F_4 and F_5 fertilizer plots and mean relative E_t (E_t/E_{to}) where adequate nitrogen appeared to have been provided. Since the time of occurrence of low moisture conditions on different treatments was not always at the same stage of growth even within one year, some scatter of points is to be expected. However, the general trend indicated yields decreased more rapidly than E_t. For example, if irrigations were delayed, causing a 10-percent reduction in seasonal E_t, yields were reduced about 20 percent. Likewise, a 20-percent reduction in E_t reduced yields about 35 percent. The same type of relation would not necessarily occur if yields included total dry matter produced.

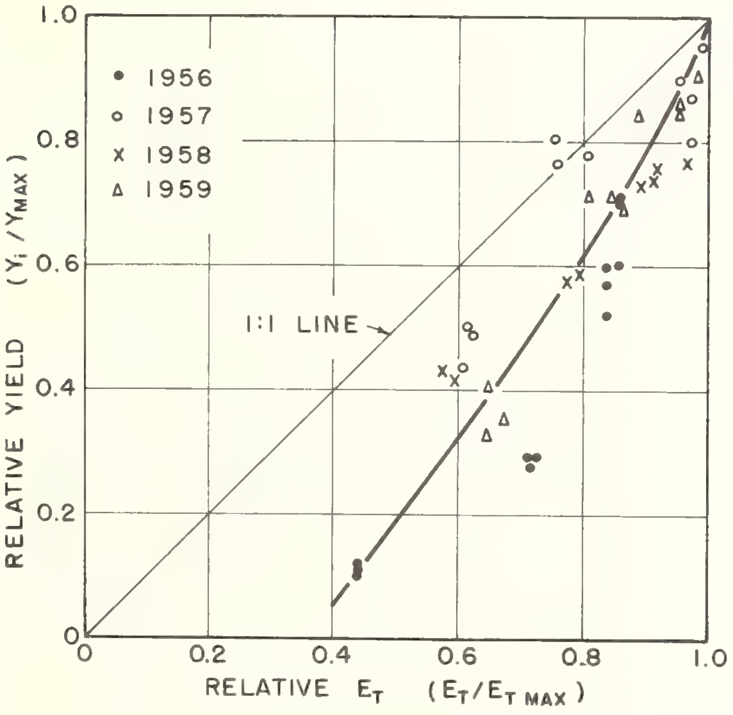

FIGURE 5.—Relative yield decreased more rapidly than relative seasonal evapotranspiration when irrigations were delayed.

Larger yields on the nitrogen-fertilized subplots in 1957–59 resulted in lower average soil moisture than on the 0-nitrogen subplots. The mean soil moisture percentages for sampling periods from July 15 to September 15 for each depth are presented in table 15 in the appendix. These values are averages of 64 to 112 soil samples. Average values cannot be used to compare moisture levels directly, because different sampling dates were involved. Differences in mean soil moisture in the 0- to 4-foot depth between the F_2 plot and the average of F_4 and F_5 plots are plotted in figure 6 against differences in yield between the two.

These results indicate that if large yield or plant-growth differences are expected between treatments and if soil moisture level is an important factor, experiments should not be designed with subplot treatments having large yield or plant-growth differences. The mean soil moisture percentage on the nitrogen-fertilized plots averaged 0.9 percent (on an oven-dry weight basis) less than the 0-nitrogen plots when yields on the nitrogen-fertilized plots were 4,000 lb./acre greater. This difference represents about 10 percent of the total available soil moisture. The difference in soil moisture tension in the upper soil layers just before irrigating may have reached several atmospheres, especially on treatments where the soil moisture tension was allowed to reach 4 or 9 atmospheres before irrigating.

Grain Quality

Soil moisture and nitrogen fertilizer affected the quality of the grain as well as the yield. Test weight and protein content were used to evaluate quality.

Test Weight

A summary of test weights for all soil moisture and fertilizer treatments and an analysis of variance are presented in table 16 in the appendix. The low 4-year average test weights on the M_1 moisture level were due primarily to greater lodging in 1958 as rate of applied nitrogen increased.

The low values on the M_2 treatment were due primarily to lodging in 1956. Lodging and low test weights appeared to have been more severe when soil moisture was adequate early in the season but deficient during the latter part of the season.

Protein

Protein content of grain was inversely related to the level of production and directly to the amount of nitrogen fertilizer applied (appendix

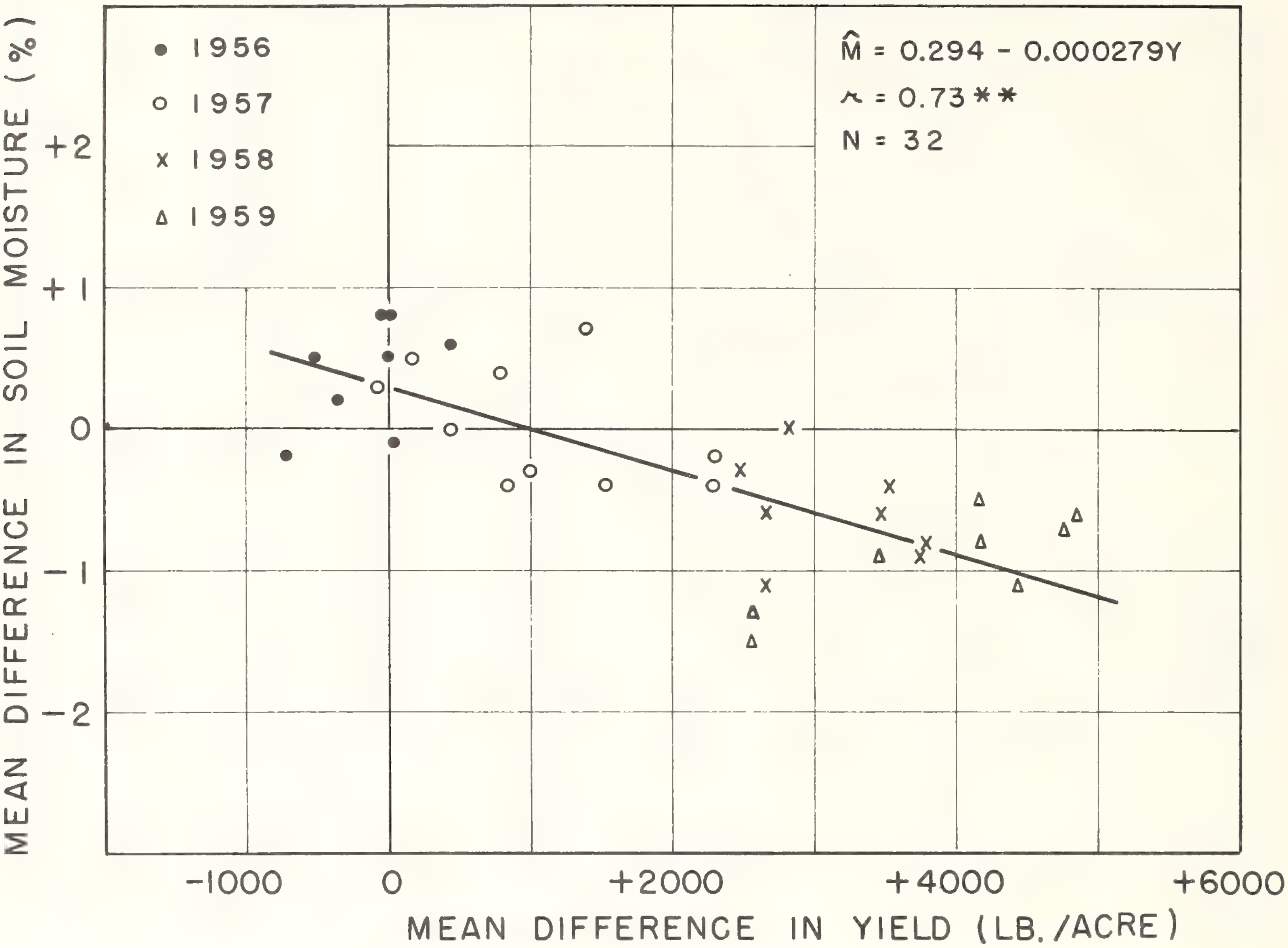

Figure 6.—Mean soil moisture content was lower on the nitrogen-fertilized plots than on the F_2 plots when large differences in yields occurred.

table 17). In 1956, the protein content averaged 15.3, 14.0, 13.4, 11.3, 12.1, and 14.3 percent for progressively increasing moisture treatments. Individual fertilizer treatments were not analyzed in 1956.

In 1957, protein content on the M_1 moisture level averaged 11.65 percent as compared with 8.30 and 8.18 percent on the M_3 and M_5 levels, respectively. The 2-year average yields (1956 and 1957) on these treatments were 2,159, 5,548, and 5,894 lb /acre, respectively. The weighted mean protein content for 1957 and 1958 was about 11 percent with average yields of about 3,000 lb. (weighted mean=sum of yield x protein content for each year/total 2-year yield). With larger yields on higher moisture levels, protein content was lower.

With average yields of about 5,000 lb./acre, protein content averaged 6.3 percent on the 0-nitrogen plots. With 240 lb./acre of nitrogen applied in 1956 and 1958, protein content averaged only 8.5 percent when yields averaged 6,400 lb./acre. Thus, protein content was maintained to a certain extent when nitrogen applications exceeded that needed for yield.

Other Crop Characteristics

Plant Height

The height of the sorghum increased with the first two increments of applied nitrogen in 1958 but decreased slightly at the highest rate. Very little difference between nitrogen rates occurred in 1957 and 1959 (table 6). Low soil moisture during the late boot stage reduced plant height. The shortest plants were on the M_1 moisture level.

Heading Dates

Date of heading was delayed on plots receiving no nitrogen (appendix table 18). Heading was earliest on the low moisture levels.

Heads per Acre and Weight per Head

The number of heads per acre and weight per head were primary components of large variations in yields in 1959. The lower yield on the low moisture levels was a result of fewer and smaller heads as compared to the higher moisture levels (tables 7 and 8). Nitrogen fertilizer increased the weight per head over the 0-nitrogen plot on the medium and optimum moisture levels (table 8). However, there was only a small difference in head weights between the 60-, 120-, and 240-lb./acre nitrogen application rates. Therefore, large differences in yield between these treatments were due primarily to the number of heads per acre.

TABLE 6.—*Average height of irrigated grain sorghum in 1957, 1958, and 1959, Bushland, Tex.*

Fertilizer No.[1]	Height at moisture level [2] of—						Average for all moisture levels
	M_1	M_2	M_3	M_4	M_5	M_6	
	Ft.	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*
F_1	3.14	3.85	3.67	4.15	4.29	3.89	3.83
F_2	3.38	3.93	3.76	3.98	4.10	3.76	3.81
F_3	3.34	3.95	3.89	4.22	4.24	3.95	3.93
F_4	3.22	3.94	3.84	4.12	4.35	3.90	3.89
F_5	3.24	3.75	3.61	4.12	4.23	3.80	3.79
F_6	3.18	3.74	3.74	4.15	4.15	3.86	3.80
Average	3.25	3.86	3.75	4.12	4.23	3.86	3.84

[1] See p. 5 for fertilizer applications.
[2] See p. 5 for irrigation schedules.

TABLE 7.—*Number of heads per acre of irrigated grain sorghum (RS–610) as affected by moisture and fertilizer treatments, Bushland, Tex., 1959*

PRODUCTION DATA

Fertilizer treatment			Heads at moisture level [1] of—						Average for all moisture levels
No.	N	P_2O_5	M_1	M_2	M_3	M_4	M_5	M_6	
	Lb./acre	*Lb./acre*	*Thousands*	*Thousands*	*Thousands*	*Thousands*	*Thousands*	*Thousands*	*Thousands*
F_1	240	0	43.5	57.3	67.3	69.0	76.0	59.5	62.1
F_2	0	30	44.8	52.8	56.0	58.3	61.5	50.5	54.0
F_3	60	30	46.5	56.0	58.8	65.0	61.0	58.8	57.7
F_4	120	30	41.8	58.0	72.3	71.0	74.3	62.3	63.3
F_5	240	30	42.0	58.5	71.5	75.3	77.5	59.8	64.1
F_6	240	60	47.8	63.3	72.5	75.5	76.8	69.5	67.5
Average	--------	--------	44.4	57.6	66.4	69.0	71.2	60.0	61.4

ANALYSIS OF VARIANCE

Component	Degrees of freedom	Mean square [2]
Moisture (M)	5	2,322.43**
Error (a)	15	29.19
Fertilizer (F)	5	566.98**
M×F	25	55.97**
Error (b)	90	14.81
Total	143	----------------------------

[1] See p. 5 for irrigation schedule.
[2] **=Significant at the 1-percent level.

TABLE 8.—*Weight per head of irrigated grain sorghum as affected by moisture and fertilizer treatments, Bushland, Tex., 1959*

PRODUCTION DATA

Fertilizer treatment			Head weight at moisture treatment [1] of—						Average for all moisture levels
No.	N	P_2O_5	M_1	M_2	M_3	M_4	M_5	M_6	
	Lb./acre	*Lb./acre*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
F_1	240	0	0. 104	0. 110	0. 113	0. 144	0. 148	0. 145	0. 127
F_2	0	30	. 083	. 093	. 086	. 076	. 073	. 086	. 082
F_3	60	30	. 098	. 115	. 125	. 134	. 133	. 142	. 124
F_4	120	30	. 101	. 112	. 117	. 141	. 135	. 139	. 124
F_5	240	30	. 106	. 111	. 110	. 142	. 140	. 141	. 125
F_6	240	60	. 102	. 099	. 114	. 133	. 141	. 131	. 120
Average			. 099	. 107	. 111	. 128	. 128	. 131	. 117

ANALYSIS OF VARIANCE

Component	Degrees of freedom	Mean square [2]
Moisture (M)	5	0. 004358**
Error (a)	15	. 000108
Fertilizer (F)	5	. 007082**
M×F	25	. 000416**
Error (b)	90	. 000057
Total	143	

[1] See p. 5 for irrigation schedule.

[2] **=Significant at the 1-percent level

Water Use Efficiency

Water use efficiency, expressed in units of marketable products per unit of water evaporated and transpired during the growing season, is frequently used to evaluate water management practices. The term indicates the relative effectiveness of agronomic and irrigation practices in maximum utilization of water supplies. Water use efficiencies for the 4 years are summarized in table 19 in the appendix.

Fertilizer Effects

Fertilizers are extremely important when attempting to obtain maximum production per unit of water. The effect of both soil moisture and nitrogen on water use efficiency after 4 years of irrigation is shown by data for 1959 (table 19). With low moisture levels, nitrogen did not increase water use efficiency greatly. When soil moisture was not limiting, nitrogen fertilizer more than doubled the production of grain per unit of water. The large difference in water use efficiency was due to the use of nitrogen, which more than doubled grain yields but increased seasonal evapotranspiration less than 10 percent.

Annual Variations

In a dry year such as 1956, water use efficiency with limited irrigations was low, but in the years of normal or above normal well-distributed precipitation, relatively high water use efficiency was also obtained with limited irrigation treatments. In contrast, medium to optimum soil moisture and adequate nitrogen fertility resulted in high water use efficiencies in seasons with below normal, normal, and above normal precipitation.

Irrigation Water Use Efficiency

Irrigation water use efficiency was evaluated by considering yield increases over nonirrigated crop yields per unit of irrigation water applied prior to planting and during the growing season. The 4-year average production of grain per acre-inch of irrigation water applied is presented in table 9. The highest 4-year average irrigation water use efficiency occurred on the optimum soil moisture level. With the irrigation practices used in this study—that is, a preplanting irrigation plus two or three 4-inch irrigations during the growing season—the largest average production of grain per unit of irrigation water required 14 to 16 acre-inches of irrigation water per acre per year.

TABLE 9.—*Effect of soil moisture level and nitrogen on the production of grain sorghum per unit of irrigation water applied annually, Bushland, Tex.*[1]

Fertilizer treatment	Increase at moisture level of—						Average for all moisture levels
No.	M_1	M_2	M_3	M_4	M_5	M_6	
	Lb./ acre-inch	*Lb./ acre-inch*	*Lb./ acre-inch*	*Lb./ acre-inch*	*Lb./ acre-inch*	*Lb./ acre-inch*	*Lb./ acre-inch*
F_2	208	288	226	222	173	207	220
F_4	230	314	340	360	308	330	314
F_5	225	328	323	379	334	345	322
Averages	221	305	296	321	272	295	286

[1] Based on the increase in yield over dryland yields of the same hybrid in 1957–59 and Early Hegari in 1956.

Fallow Period Irrigations

Irrigation before planting is practiced in the High Plains to assure a stand, to maintain growth until irrigation furrows can be made, and to germinate grain not removed during harvest. Irrigation of wheat is generally not economical after May 20, as yields will not be materially affected. Thus the irrigation wells can be used for preplanting irrigations for grain sorghum several weeks prior to the optimum time to plant. Also, because of the low intake rates, a preplanting irrigation is often made to store water in the 3- to 5-foot depth of the soil profile. Storing water in the 3- to 5-foot depth allows the farmer to irrigate more acres with a given water supply. If irrigations are made only after planting, the demand for water may be greater than the capacity of the wells when E_t rates are high. Without water storage in the 3- to 5-foot depth, severe reductions in yield can occur.

Storage of rainfall during the fallow period is usually 15 to 20 percent of the offseason precipitation with dryland farming. About 25 percent of the total precipitation at Amarillo comes from storms bringing less than 0.25 inch each. Nearly 70 percent of the precipitation comes from storms bringing less than 1 inch each (*5*). With these light showers, penetration into the fine-textured soil is limited and evaporation losses are high.

Storage efficiency of precipitation plus irrigation water applied offseason was also low. The 3-year average fallow season precipitation was 11.18 inches on the M_1 plots and 10.95 on the M_4 plots. However, because of high evaporation losses, preplanting irrigations were necessary to wet the soil profile to a depth of 6 feet. The average depth of preplanting irrigation was 5.5 and 5.2 inches for a total of 16.7 and 16.1 inches of precipitation plus irrigation water on the M_1 and M_4 moisture levels, respectively. The average net gain in soil moisture from harvest to planting was 5.5 and 4.2 inches. Thus, the efficiency of storing precipitation plus irrigation water was 33 percent on the M_1 plots and 26 percent on the M_4 plots. This loss of water, primarily by evaporation, was approximately one-half the amount required to grow a crop of winter wheat during the same period. The total depth of water evaporated and transpired annually on the grain sorghum plots with optimum soil moisture was about 34 inches.

Irrigation Water Management

Irrigation water management practices for grain sorghum will vary with each farm unit, depending upon the crops grown, available water supply, general level of production desired, and facilities and labor for irrigating. Some general irrigation guidelines can be derived from the results of this study.

Preplanting Irrigations

Under normal climatic conditions and recommended irrigation practices, the soil profile will be near the wilting percentage in the top 4 feet at harvest. As indicated in table 1, about 6 inches of available water could then be stored in the 0- to 4-foot depth. From table 3, the average precipitation during the fall and winter months in this area is about 7 inches. However, from November through March approximately one-half of this precipitation comes from storms bringing less than one-half inch each, resulting in high evaporation losses. Therefore, unless large rains are received in April and May, the soil will generally not be wet to more than 1 to 2 feet by planting time. With these soil moisture conditions, preplanting irrigations may be more convenient than applying greater amounts of water after planting.

High Production Level

If it is assumed that adequate fertilizer was provided for near maximum production and a preplanting irrigation was given, irrigations can be scheduled by (1) observing rainfall that has occurred, (2) estimating probable rainfall based on current forecasts for 4 to 5 days ahead, and (3) utilizing the mean cumulative E_t or E_t rate curve of figure 2 or 3. For high yields, only about 50 percent of available water can be depleted before irrigating the first time when the root system is not fully developed. Thus, the first irrigation should be applied to the entire field before 3 to 3.5 inches are used from the soil. With normal precipitation in June and July and a planting date near June 15, the first irrigation will be needed in late July or early August, depending on actual rainfall. The second irrigation will be needed about August 15, allowing 3 to 3.5 inches to be depleted from the soil after the first irrigation. The third irrigation, and probably the last, would be needed between September 5 and 10. A season with below normal precipitation would require four irrigations with the first one beginning sooner than indicated, whereas a season with above normal precipitation may require only two irrigations, each irrigation requiring 3.5 to 4 inches of water.

Medium Production Level

If adequate fertilizer and a preplanting irrigation are assumed, the first irrigation for the medium production level should be given before 3.5 to 4 inches of soil moisture are used. With normal climatic conditions, the first irrigation will be needed about the first week in August. The second, and perhaps the last irrigation, should be given when about 5 inches of soil moisture are used after the first irrigation. With about 2.5 inches of average rainfall in August, this irrigation will be needed about September 1. A dry season would require three irrigations and a wet season perhaps only one irrigation, scheduled in a similar manner.

Low Production Level

If limited water supply or pumping capacity during the summer is anticipated, irrigation for a low production level may be necessary. The planting rate should be reduced to rates near those used for dryland farming. If a preplanting irrigation was given, then the first and only irrigation during the growing season should be given when the plants begin to show signs of severe wilting during the day. Preferably, this irrigation should be delayed until the middle or latter part of August during the milk stage. The yield with this practice will not be high, but it will be greater than dryland yields. Fertilizer requirements will be considerably less at this level of production. Lodging caused by charcoal rot may be severe some years with these limited irrigation practices.

SUMMARY AND CONCLUSIONS

The 4-year study of irrigated grain sorghum, with six soil moisture levels and each with six fertilizer treatments, showed that seasonal evapotranspiration (E_t) will average about 22 inches from planting to harvest when irrigating and fertilizing for high yields (fig. 2). Nitrogen fertilizer increased yields 2 to 2½ times more than those from plots receiving no nitrogen, but increased seasonal E_t only about 6 percent.

The rate of E_t shortly after planting grain sorghum in June was less than 0.1 inch per day, even though solar radiation and air temperatures were high. As amount of vegetation increased, the E_t rate increased rapidly, reaching a maximum of about 0.30 inch per day during the early part of August (fig. 3). During August and until harvest, the E_t rate decreased as solar radiation, air temperature, and soil moisture decreased, and as the plants matured.

Grain sorghum yields were greatly affected by the soil moisture level. Yields were also greatly affected by the rate of nitrogen application in the third and fourth year after beginning to irrigate Pullman soil. To maintain yields of 6,000 to 7,000 lb./acre, at least 120 lb./acre of nitrogen were required annually after 2 years of irrigation (table 4). With limited irrigations that restricted yields to 2,500 to 3,000 lb./acre, nitrogen fertilizer was not needed.

Yields were less than 6,000 to 7,000 lb. per acre when more than 80 percent of the available water in the 0- to 4-foot depth had been depleted before irrigating (fig. 4). Delayed irrigations reduced seasonal E_t by 10 to 20 percent, but yields were reduced 20 to 35 percent (fig. 5). Severe lodging caused by charcoal rot and low test weights occurred when soil moisture was adequate early in the season but inadequate late in the season.

High water use efficiency was greatly dependent on nitrogen fertilizer. Nitrogen fertilizer doubled the production of grain produced per unit of water (appendix table 19). High average water use efficiency occurred when optimum soil moisture was maintained. During years with well-distributed precipitation, lower moisture levels also resulted in high water use efficiencies.

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APPENDIX

Table 10.—*Record of irrigations and stage of growth of grain sorghum at Bushland, Tex., 1956–59*

Time of irrigation		Irrigation for moisture level of—					
Date	Stage of plant growth	M_1	M_2	M_3	M_4	M_5	M_6
1956		*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Apr. 3	Preplanting	4. 0	4. 0	4. 0	4. 0	4. 0	4. 0
June 27	Emergence	3. 0	3. 0	3. 0	3. 0	3. 0	3. 0
July 26	24-in. height					3. 5	
July 30	26-in. height				4. 0		
July 31	26-in. height		4. 0				4. 0
Aug. 6	Boot			4. 0			
Aug. 11	Boot					4. 0	
Aug. 15	Flower				4. 0		4. 0
Aug. 30	Milk			4. 0		4. 0	
Sept. 4	Soft dough				4. 0		
Total		7. 0	11. 0	15. 0	19. 0	18. 5	15. 0
1957							
June 8	Preplanting	5. 5	5. 5	5. 5	5. 5	5. 5	5. 5
July 24	18-in. height				4. 0	4. 0	
Aug. 3	Boot		4. 0	4. 0			4. 0
Aug. 30	Milk					4. 0	
Sept. 3	Milk				4. 0		
Sept. 6	Milk						4. 0
Sept. 13	Soft dough			4. 0			
Sept. 20	Maturation					4. 0	
Total		5. 5	9. 5	13. 5	13. 5	17. 5	13. 5
1958							
May 30	Preplanting	5. 0	5. 0	5. 0	5. 0	5. 0	5. 0
Aug. 8	Boot					3. 0	
Aug. 12	Flower		4. 0		4. 0		
Aug. 19	Flower			4. 0		4. 0	4. 0
Aug. 30	Milk				4. 0		
Sept. 3	Milk					4. 0	
Sept. 5	Soft dough						4. 0
Sept. 9	Soft dough			4. 0			
Total		5. 0	9. 0	13. 0	13. 0	16. 0	13. 0
1959							
June 3	Preplanting	6. 0	6. 0	5. 0	5. 0	5. 0	5. 0
July 24	16-in. height					4. 0	
July 31	20-in. height				4. 0		4. 0
Aug. 4	Boot		4. 0	4. 0			
Aug. 7	Boot					4. 0	
Aug. 19	Flower				4. 0		4. 0
Sept. 2	Soft dough					3. 25	
Sept. 15	Hard dough			4. 5	4. 5		
Total		6. 0	10. 0	13. 5	17. 5	16. 25	13. 0
Average, 1956–59		5. 88	9. 88	13. 75	15. 75	17. 06	13. 62

TABLE 11.—*Rainfall during growing seasons 1956–59 near the experimental site, Bushland, Tex.*

1956		1957		1958		1959	
Date	Amount	Date	Amount	Date	Amount	Date	Amount
	Inches		*Inches*		*Inches*		*Inches*
June 18	0.12	June 23	0.90	June 20	0.31	June 22	0.95
25	.34	29	.11	28	1.12	27	.03
July 3	.29	July 26	.06	July 4–5	3.30	28	.54
4	.01	29	1.20	15	.17	30	.73
9	.05	Aug. 3–4	1.93	19	.17	July 10	.57
13	1.55	5	.01	20	1.33	12	.07
17	.11	10	.01	22	.29	14	.11
18	.02	14	1.87	24	.70	15	.60
20–23	.29	16	.19	25–27	1.27	17	.03
25	.18	25	.10	Aug. 2	.18	Aug. 7	.11
30	.56	28	.13	8	.34	8	.60
Aug. 1	.14	Sept. 1	.16	16	.04	15	.10
2	.28	6	.60	Sept. 6	1.11	21	.08
18–19	1.14	7	.02	13	.05	22–23	1.05
Sept. 5	.12	Oct. 7	.39	15	.26	30	.50
Oct. 18	.28	12	1.22	25	.33	Sept. 18	.80
20	.06	22	.59	26	.11	24	.13
		26	.36			Sept. 30–Oct. 2	.91
Total	5.42		9.85		11.08		7.91

TABLE 12.—*Effect of soil moisture levels and fertilizer (treatments F_2, F_4, and F_5) on total evapotranspiration by hybrid grain sorghum in 1956–59*

EVAPOTRANSPIRATION DATA

Year	Fertilizer treatment			Evapotranspiration at moisture level of—						Average for all moisture levels
	No.	Nitrogen	P_2O_5	M_1	M_2	M_3	M_4	M_5	M_6	
				Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1956	F_2	0	30	------	------	------	------	------	------	------
	F_4	120	30	------	------	------	------	------	------	------
	F_5	240	30	------	------	------	------	------	------	------
Average	------	------	------	12.3	15.7	18.8	21.9	23.7	18.4	18.5
1957	F_2	0	0	12.8	17.1	20.0	20.4	23.7	20.9	19.2
	F_4	0	0	13.1	16.0	20.6	20.5	23.3	20.6	19.0
	F_5	0	0	13.0	16.0	20.2	21.2	23.6	21.0	19.2
Average	------	------	------	13.0	16.3	20.3	20.7	23.5	20.8	19.1
1958	F_2	0	30	14.8	19.5	20.6	21.0	23.4	20.8	20.0
	F_4	120	30	15.4	19.7	20.3	22.3	23.1	21.8	20.4
	F_5	240	30	14.8	18.4	21.8	22.9	24.7	22.5	20.9
Average	------	------	------	15.0	19.2	20.9	22.1	23.7	21.7	20.4
1959	F_2	0	30	11.6	16.2	16.5	19.8	20.5	17.4	17.0
	F_4	120	30	12.0	16.2	19.1	20.8	22.2	19.0	18.2
	F_5	240	30	12.4	16.6	18.6	20.9	22.8	20.3	18.6
Average	------	------	------	12.0	16.3	18.1	20.5	21.8	18.9	17.9
Average of 1957–59	F_2	------	------	13.1	17.6	19.0	20.4	22.5	19.7	18.7
	F_4	------	------	13.5	17.3	20.0	21.2	22.9	20.5	19.2
	F_5	------	------	13.4	17.0	20.2	21.7	23.7	21.3	19.6
Overall average	------	------	------	13.3	17.3	19.7	21.1	23.0	20.5	19.2
1956–59 average of F_4 and F_5	------	------	------	13.2	16.8	19.8	21.6	23.4	20.2	19.2

ANALYSIS OF VARIANCE

Component	Degrees of freedom	Mean squares [1]		
		1957	1958	1959
Moisture (M)	5	172.98**	110.99**	144.07**
Error (a)	15	1.05	1.14	.59
Fertilizer (F)	2	.22	4.67**	10.84**
M × F	10	.61	2.08**	1.04*
Error	36	.47	.44	.43
Total	71	------	------	------

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[1] *=Significant at the 5-percent level; **=significant at the 1-percent level.

TABLE 13.—*Total water in the 0- to 4-foot soil profile for each date of sampling (average of the F_4 and F_5 fertilized subplots)*[1]

Year	Total water at moisture level of—											
	M_1		M_2		M_3		M_4		M_5		M_6	
	Date	Water	Date	Water	Date	Water	Date	Water	Date	Water	Date	Water
		Inches		*Inches*		*Inches*		*Inches*		*Inches*		*Inches*
1956	July 5–6	14.4	July 5–6	14.4	July 5–6	14.4	July 5–6	14.4	July 5–6	14.4	July 5–6	14.4
	July 18–19	13.7	July 18–19	13.7	July 18–19	13.7	July 18–19	13.7	July 18–19	13.7	July 18–19	13.7
	Aug. 2	11.8	July 30	12.2	Aug. 2	11.8	July 26	12.7	July 26	12.7	July 30	12.3
	Aug. 20–21	10.9	Aug. 7	14.1	Aug. 13–14	12.4	July 30	12.2	Aug. 6	14.0	Aug. 7	14.1
	Sept. 11	9.1	Aug. 16	11.0	Aug. 24	11.0	Aug. 6	14.3	Aug. 10	12.2	Aug. 15	11.4
	Oct. 8–12	8.8	Sept. 1	10.0	Sept. 10	11.5	Aug. 15	11.2	Aug. 24	[2] 13.7	Aug. 31	11.8
			Sept. 17	9.0	Oct. 22	9.6	Sept. 4	11.3	Aug. 27	12.6	Sept. 12	10.2
			Oct. 16	8.9			Sept. 14	12.4	Sept. 11	12.9	Oct. 18	9.6
							Sept. 17	11.8	Oct. 30	9.4		
							Nov. 1–2	9.7				
1957	July 9	[2] 14.6	July 9	[2] 14.6	July 9	[2] 14.2	July 9	[2] 14.7	July 9	[2] 14.8	July 9	[2] 14.4
	July 23	13.2	July 23	12.9	July 23	12.4	July 23	13.0	July 23	13.4	July 23	12.7
	Aug. 13	11.8	Aug. 3	11.8	Aug. 3	11.6	Aug. 3	14.9	Aug. 3	15.1	Aug. 3	11.9
	Aug. 29	11.8	Aug. 12	14.5	Aug. 12	14.2	Aug. 23	14.2	Aug. 23	14.3	Aug. 13	14.3
	Sept. 20	10.2	Aug. 29	13.6	Aug. 29	13.4	Sept. 3	12.1	Aug. 29	13.3	Aug. 29	13.7
			Sept. 20	11.0	Sept. 12	12.0	Sept. 18	14.0	Sept. 9	14.5	Sept. 5	12.6
					Sept. 23	13.2	Oct. 11	11.0	Sept. 20	12.6	Sept. 18	13.9
					Oct. 11	11.0			Oct. 2	14.4	Oct. 11	10.8
									Oct. 11	13.2		
1958	June 23	15.0	June 23	15.0	June 23	14.8	June 23	15.2	June 23	15.4	June 23	15.2
	July 31	15.0	July 31	15.2	July 31	14.8	July 15	15.1	Aug. 4	15.1	Aug. 4	14.5
	Aug. 18	10.7	Aug. 11	12.7	Aug. 18	11.0	Aug. 4	14.8	Aug. 18	13.0	Aug. 18	11.0
	Oct. 6	10.5	Aug. 18	13.8	Aug. 27	13.5	Aug. 11	12.8	Aug. 27	15.2	Aug. 27	13.7
			Sept. 15	10.5	Sept. 9	11.6	Aug. 18	14.1	Sept. 2	12.7	Sept. 4	11.4
			Oct. 6	10.7	Sept. 18	13.0	Aug. 29	11.9	Sept. 15	14.9	Sept. 18	14.5
					Oct. 11	13.6	Sept. 15	13.1	Sept. 29	13.6	Oct. 13	11.6
							Sept. 29	12.1	Oct. 13	12.4		
							Oct. 11	11.6				
1959	June 2	11.1	June 2	11.1	June 2	12.3	June 2	12.3	June 2	12.6	June 2	12.2
	June 25	14.9	June 25	15.3	June 25	15.6	June 25	15.5	June 25	15.8	June 25	15.5
	July 22	14.0	July 22	14.0	July 22	14.2	July 22	14.8	July 22	14.2	July 22	14.2
	Aug. 11	10.9	Aug. 3	11.9	Aug. 3	12.1	July 30	13.1	July 30	15.6	July 30	12.8
	Aug. 31	10.4	Aug. 11	14.5	Aug. 11	14.0	Aug. 4	15.8	Aug. 7	13.0	Aug. 4	15.1
	Sept. 14	9.6	Aug. 31	12.0	Aug. 31	11.9	Aug. 18	12.6	Aug. 12	15.9	Aug. 18	12.4
	Oct. 7	10.4	Sept. 14	10.2	Sept. 14	10.3	Sept. 1	14.4	Sept. 1	12.7	Sept. 1	14.0
			Oct. 7	10.6	Sept. 23	12.6	Sept. 15	12.2	Sept. 8	14.1	Sept. 14	12.0
					Oct. 8	13.1	Sept. 23	14.8	Oct. 8	12.3	Oct. 8	11.4
							Oct. 8	14.6				

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[1] Each value is based on 8 soil cores except in 1956, when several moisture levels sampled the same day are averaged together. Water content at wilting point is about 9.3 inches.

[2] Average of F_2, F_4, and F_5.

TABLE 14.—*Total water in the 4- to 6-foot increment of the soil profile for each date sampled (average of F_4 and F_5 fertilizer subplots)*[1]

Year	Total water at moisture level of—											
	M_1		M_2		M_3		M_4		M_5		M_6	
	Date	Water	Date	Water	Date	Water	Date	Water	Date	Water	Date	Water
		Inches		*Inches*		*Inches*		*Inches*		*Inches*		*Inches*
1956	July 5–6	5.5	July 5–6	5.5	July 5–6	5.5	July 5–6	5.5	July 5–6	5.5	July 5–6	5.5
	Aug. 2	5.6	Sept. 1	5.5	Aug. 2	5.5	Nov. 1–2	5.0	Oct. 30	5.2	Aug. 31	6.4
	Aug. 20–21	5.7	Oct. 16	5.2	Aug. 13–14	5.4					Oct. 18	5.8
	Oct. 8–12	4.7			Sept. 10	5.5						
					Oct. 22	5.6						
1957	July 9	[2] 5.3	July 9	[2] 5.5								
	Aug. 13	5.0	Sept. 20	5.9								
	Sept. 20	4.9										
1958	June 23	6.1	June 23	6.8	June 23	6.9	June 23	6.8	June 23	7.2	June 23	7.1
	Oct. 6	6.1	Sept. 15	6.6	Oct. 11	6.6	July 15	7.6	Oct. 13	6.9	Oct. 13	6.5
			Oct. 6	6.6			Oct. 11	6.6				
1959	June 25	6.5	June 25	6.8	June 25	7.2	June 25	7.1	June 25	7.5	June 25	7.1
	Aug. 11	6.1	Sept. 14	6.0	Oct. 8	6.2	Oct. 8	6.7	Oct. 8	6.7	Oct. 8	6.6
	Oct. 7	5.8	Oct. 7	6.1								

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[1] Each value is based on 8 soil cores except in 1956, when several moisture levels sampled on the same day were averaged together. Water content at wilting point is about 4.7 inches.

[2] Average of F_2, F_4, and F_5.

TABLE 15.—*Average soil moisture percentage on an oven-dry weight basis for sampling periods between July 15 and Sept. 15*

Year	Depth	Soil moisture at moisture levels and fertilizer rates of—																	
		M_1			M_2			M_3			M_4			M_5			M_6		
		F_3	F_4	F_5	F_3	F_4	F_5	F_3	F_4	F_5	F_3	F_4	F_5	F_3	F_4	F_5	F_3	F_4	F_5
	Ft.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1956	0–1	16.8	16.5	15.8	16.8	16.9	16.7	18.1	17.7	17.6	17.0	17.7	17.3	18.2	18.8	18.4	16.9	17.2	16.8
	1–2	16.8	16.8	16.4	17.8	17.9	17.8	18.0	18.3	18.2	18.4	18.9	19.0	18.9	19.7	19.9	18.0	18.2	18.1
	2–3	15.7	15.8	15.3	16.6	17 0	16.9	16.2	15.9	16.0	16.8	17.3	17.6	16.8	17.7	18.1	16.2	17.0	16.9
	3–4	16.0	16.0	15.4	16.5	17.4	16.4	16.7	16.5	16.0	16.3	17.0	16.7	16.5	17.5	17.3	16.4	17.0	16.5
Average		16.3	16.3	15.7	16.9	17.3	17.0	17.2	17.1	17.0	17.1	17.7	17.6	17.6	18.4	18.4	16.9	17.4	17.1
1957	0–1	16.5	16.7	15.7	17.6	18.1	18.3	18.2	18.0	17.2	19.2	19.2	19.5	20.5	21.0	19.8	17.4	17.8	17.2
	1–2	18.3	18.6	18.2	19.0	19.3	18.8	19.3	18.6	18.7	20.6	20.0	20.2	20.8	20.8	20.5	18.8	19.3	19.4
	2–3	17.3	17.6	17.5	18.7	19.0	19.0	18.2	17.4	17.9	19.6	19.0	18.9	19.1	20.2	19.1	18.0	18.6	18.7
	3–4	16.3	17.0	17.0	18.0	18.2	18.0	17.2	17.5	17.4	18.4	18.0	17.6	17.7	18.6	17.9	17.3	18.0	18.0
Average		17.1	17.5	17.1	18.3	18.6	18.5	18.2	17.9	17.8	19.4	19.0	19.0	19.5	20.2	19.3	17.9	18.4	18.3
1958	0–1	19.6	18.8	18.0	19.6	20.2	18.9	21.2	20.0	19.6	20.9	19.8	19.2	21.9	21.3	20.6	19.2	19.1	18.4
	1–2	19.0	18.3	18.2	18.6	19.2	19.3	19.2	18.3	17.2	20.6	19.8	19.7	21.5	20.5	20.4	18.4	18.2	18.9
	2–3	18.4	17.3	17.2	16.7	17.2	17.1	16.8	16.5	16.1	18.6	18.8	18.0	20.0	19.0	19.1	16.4	16.0	17.0
	3–4	18.4	18.5	18.0	17.0	17.1	17.6	17.8	18.0	17.9	19.2	19.3	18.9	18.9	19.2	18.7	18.0	17.6	17.6
Average		18.8	18.2	17.8	18.0	18.4	18.2	18.8	18.2	17.7	19.8	19.4	19.0	20.6	20.0	19.7	18.0	17.7	18.0
1959	0–1	16.5	15.8	15.4	19.0	17.9	17.9	19.7	18.0	18.1	20.6	19.3	19.3	21.5	20.8	20.3	20.2	19.2	19.0
	1–2	16.5	16.2	15.9	18.8	17.9	17.5	19.1	17.7	17.3	20.9	19.8	19.7	21.5	20.6	20.8	20.6	19.2	19.4
	2–3	15.4	15.3	15.0	17.8	17.2	16.7	18.0	16.8	16.7	19.4	19.2	19.2	20.3	19.5	19.9	19.4	18.4	18.5
	3–4	15.8	16.3	17.1	17.6	17.9	17.8	19.2	18.5	17.9	19.4	19.6	19.6	20.1	19.5	19.5	19.3	18.6	19.0
Average		16.0	15.9	15.8	18.3	17.7	17.5	19.0	17.7	17.5	20.0	19.5	19.4	20.8	20.0	20.1	19.9	18.8	19.0
Overall average		17.1	17.0	16.6	17.9	18.0	17.8	18.3	17.7	17.5	19.1	18.9	18.8	19.7	19.7	19.4	18.2	18.1	18.1

TABLE 16.—*Effect of soil moisture and fertilizer treatments on the test weight of hybrid grain sorghum for 1956–59*

TEST WEIGHT DATA

Year	Fertilizer treatment			Weight for moisture treatment of—						Average for all treatments
	No.	Nitrogen	P_2O_5	M_1	M_2	M_3	M_4	M_5	M_6	
	Lb./acre	*Lb./acre*	*Lb./bu.*	*Lb./bu.*	*Lb./bu.*	*Lb./bu.*	*Lb./bu.*	*Lb./bu.*	*Lb./bu.*	*Lb./bu.*
1956	F_1	240	0	56.3	47.5	57.0	58.4	57.7	54.1	55.2
	F_2	0	30	56.7	50.2	57.5	58.6	57.7	54.6	55.9
	F_3	60	30	56.3	49.7	57.3	58.6	57.9	55.2	55.8
	F_4	120	30	56.3	50.6	57.3	58.5	57.8	55.1	56.0
	F_5	240	30	56.1	47.3	57.0	57.1	58.2	54.8	55.1
	F_6	240	60	56.4	48.2	56.8	58.6	57.4	55.1	55.4
Average				56.4	48.9	57.1	58.3	57.8	54.8	55.6
1957	F_1	0	0	57.2	58.6	58.3	59.0	58.9	58.3	58.4
	F_2	0	0	56.4	58.2	57.8	58.2	58.4	58.2	57.9
	F_3	0	0	56.6	58.1	58.1	58.6	58.0	57.9	57.9
	F_4	0	0	56.8	58.2	58.2	58.8	58.3	58.0	58.0
	F_5	0	0	57.4	58.6	58.7	59.1	59.0	58.6	58.6
	F_6	0	0	57.4	58.6	58.5	58.8	59.2	58.4	58.5
Average				57.0	58.4	58.3	58.8	58.6	58.2	58.2
1958	F_1	240	0	49.8	57.1	59.4	59.3	58.8	59.6	57.3
	F_2	0	30	55.2	59.0	58.1	58.0	57.6	58.5	57.7
	F_3	60	30	51.9	58.8	58.8	59.1	58.5	59.2	57.7
	F_4	120	30	49.8	58.4	59.4	59.2	59.1	59.5	57.6
	F_5	240	30	49.8	58.0	59.6	59.6	59.0	59.8	57.6
	F_6	240	60	50.5	58.2	59.6	59.4	59.3	59.4	57.7
Average				51.2	58.2	59.2	59.1	58.7	59.3	57.6
1959	F_1	240	0	57.2	57.1	57.1	57.9	58.5	58.2	57.6
	F_2	0	30	58.9	58.4	57.4	57.3	56.8	58.0	57.8
	F_3	60	30	58.3	58.6	58.1	58.2	58.6	58.8	58.4
	F_4	120	30	57.8	57.3	58.0	58.3	57.8	59.1	58.0
	F_5	240	30	58.2	57.4	56.2	58.3	58.7	59.0	57.9
	F_6	240	60	58.2	57.3	57.5	56.7	59.0	59.0	57.9
Average				58.1	57.7	57.4	57.8	58.2	58.7	57.9
1956–59 average	F_1			55.1	55.1	58.0	58.6	58.5	57.6	57.1
	F_2			56.8	56.4	57.7	58.0	57.6	57.3	57.3
	F_3			55.8	56.3	58.1	58.6	58.2	57.8	57.4
	F_4			55.2	56.1	58.2	58.7	58.2	57.9	57.4
	F_5			55.4	55.3	57.9	58.5	58.7	58.0	57.3
	F_6			55.6	55.6	58.1	58.4	58.7	58.0	57.4
Overall average				55.7	55.8	58.0	58.5	58.3	57.8	57.3

ANALYSIS OF VARIANCE

Component	Degrees of freedom	Mean squares [1]			
		1956	1957	1958	1959
Moisture (M)	5	289.35**	10.11**	243.95**	5.00**
Error (a)	15	3.05	.46	1.99	1.05
Fertilizer (F)	5	3.50**	2.30**	.61	1.66*
M × F	25	1.49*	.12	4.96**	1.66**
Error (b)	90	.75	.27	1.48	.61
Total	143				

[1] *=Significant at the 5-percent level; **=significant at the 1-percent level.

TABLE 17.—*Grain protein percentage*[1] *as influenced by moisture and fertilizer treatments on irrigated grain sorghum*

PROTEIN DATA

Year	Nitrogen	Protein at moisture level of—			Average for 3 moisture levels
		M_1	M_3	M_5	
		Pct.	*Pct.*	*Pct.*	*Pct.*
1957 [2]	F_2	11. 64	6. 86	8. 19	8. 90
	F_3	12. 16	8. 06	8. 06	9. 43
	F_4	11. 76	8. 76	8. 03	9. 52
	F_5	11. 02	9. 54	8. 44	9. 67
Average		11. 65	8. 30	8. 18	9. 38
1958	F_2	9. 38	4. 85	4. 81	6. 35
	F_3	11. 73	5. 51	5. 23	7. 49
	F_4	10. 78	7. 09	6. 76	8. 21
	F_5	11. 72	9. 63	8. 65	10. 00
Average		10. 92	6. 77	6. 36	8. 02
1960 [2,3]	F_2	4. 56	4. 06	4. 11	4. 24
	F_3	6. 01	4. 27	4. 20	4. 83
	F_4	6. 90	4. 65	4. 22	5. 26
	F_5	7. 10	7. 21	6. 54	6. 95
Average		6. 14	5. 05	4. 77	5. 32
Average, 1957, 1958, 1960	F_2	8. 52	5. 26	5. 70	6. 49
	F_3	9. 97	5. 95	5. 83	7. 25
	F_4	9. 84	6. 83	6. 34	7. 67
	F_5	9. 95	8. 79	7. 88	8. 87
Overall average		9. 57	6. 71	6. 44	7. 57

ANALYSIS OF VARIANCE

Component	Degrees of freedom	Mean squares [4]		
		1957	1958	1960
Moisture (M)	2	46. 45**	76. 50**	6. 34
Error (a)	4	. 36	. 99	1. 13
Fertilizer (F)	3	1. 00	31. 80**	18. 35**
M × F	6	1. 83**	3. 86**	1. 83*
Error (b)	18	. 37	. 79	. 55
Total	35			

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[1] Percentage of protein=percentage of nitrogen x 5.70.

[2] Residual applied nitrogen.

[3] Residual moisture treatment.

[4] *=Significant at the 5-percent level; **=significant at the 1-percent level.

TABLE 18.—*Effect of soil moisture level and fertilizer on the stage of plant development on August 13, 1957, and August 12, 1958*

[Numerical rating: (1) late boot stage; (2) beginning to head; (3) partially headed; and (4) headed and blooming]

PLANT DEVELOPMENT DATA

Year	Fertilizer treatment	Plant rating for moisture level of—						Average for all moisture levels
		M_1	M_2	M_3	M_4	M_5	M_6	
1957	F_1	2.8	2.5	2.2	2.0	2.8	1.8	2.4
	F_2	1.8	1.8	1.2	1.0	1.2	1.2	1.4
	F_3	2.8	1.5	1.2	1.5	1.2	2.2	1.8
	F_4	2.5	2.0	1.5	1.5	1.5	1.2	1.7
	F_5	2.8	3.2	2.0	2.2	2.5	2.2	2.5
	F_6	3.2	2.8	2.2	2.0	2.5	1.5	2.4
Average		2.6	2.3	1.8	1.7	2.0	1.7	2.0
1958	F_1	3.3	2.8	3.0	3.3	3.0	3.0	3.0
	F_2	2.0	1.8	1.3	1.3	1.5	1.8	1.6
	F_3	3.5	3.3	2.5	3.3	3.0	3.3	3.1
	F_4	3.5	3.3	3.3	3.8	3.3	3.3	3.4
	F_5	3.8	3.5	3.5	3.5	3.8	3.8	3.6
	F_6	4.0	4.0	3.8	3.3	3.5	3.5	3.7
Average		3.3	3.1	2.9	3.0	3.0	3.1	3.1

ANALYSIS OF VARIANCE

Component	Degrees of freedom	Mean squares [1]	
		1957	1958
Moisture (M)	5	3.40**	0.60
Error (a)	15	.47	.40
Fertilizer (F)	5	5.00**	14.20**
M × F	25	.45	.04
Error (b)	90	.38	.29
Total	143		

[1] **=Significant at the 1-percent level.

TABLE 19.—*Effect of soil moisture and fertilizer treatments on water use efficiency (lb./acre-inch of water use) by hybrid grain sorghum*

WATER EFFICIENCY DATA

Year	Fertilizer treatment			Water use for moisture level of —						Average for all moisture levels
	No.	Nitrogen	P_2O_5	M_1	M_2	M_3	M_4	M_5	M_6	
				Lb. per acre-inch	*Lb. per acre-inch*	*Lb. per acre-inch*	*Lb. per acre-inch*	*Lb. per acre-inch*	*Lb. per acre-inch*	*Lb. per acre-inch*
1956	F_2	0	30	--------	--------	--------	--------	--------	--------	--------
	F_4	120	30	--------	--------	--------	--------	--------	--------	--------
	F_5	240	30	--------	--------	--------	--------	--------	--------	--------
Average	--------	--------	--------	60	132	253	298	225	216	197
1957	F_2	0	0	261	344	287	255	225	305	280
	F_4	0	0	284	364	329	329	288	317	319
	F_5	0	0	292	378	328	355	323	341	336
Average	--------	--------	--------	278	362	314	313	279	321	311
1958	F_2	0	30	200	269	173	164	144	184	189
	F_4	120	30	170	258	307	313	295	290	272
	F_5	240	30	165	285	286	316	286	296	272
Average	--------	--------	--------	178	270	255	264	241	256	244
1959	F_2	0	30	242	205	195	150	144	145	180
	F_4	120	30	284	278	302	344	320	312	307
	F_5	240	30	265	277	307	374	337	295	309
Average	--------	--------	--------	264	255	268	289	267	251	265
Average 1957–59	F_2	--------	--------	234	273	218	190	171	211	216
	F_4	--------	--------	246	300	313	329	301	306	299
	F_5	--------	--------	241	313	307	348	315	311	306
Overall average	--------	--------	--------	195	254	272	291	253	261	254

ANALYSIS OF VARIANCE

Component	Degrees of freedom	Mean squares[1]		
		1957	1958	1959
Moisture (M)	5	11,419**	13,679**	2,271
Error (a)	15	1,523	636	1,104
Fertilizer (F)	2	20,196**	55,390**	144,507**
M × F	10	1,252	8,395**	6,540**
Error (b)	36	857	674	942
Total	71	----------	----------	----------

[1] **=Significant at the 1-percent level.

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